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Analytical Predictions of Fatigue Crack Growth in the Lower Plate of the F-111 Wing Pivot Fitting Fuel Flow Hole Number 58

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DSTO-TN-0135

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Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

This report details a comparison of fatigue growth predictions for a fatigue crack in the lower plate of the F-111 Wing Pivot Fitting, adjacent to Fuel Flow Hole No 58. This is a known fatigue critical location and is designated as DI 86. Fatigue analysis using conventional fracture mechanics techniques and empirical retardation models performed by the manufacturer, Lockheed Martin Tactical Aircraft Sytems (then General Dynamics), predicted a fatigue life of approximately 57,000 flight hours. An equivalent analysis was conducted using the analytical crack closure code, FASTRAN II, and this resulted in a life prediction of about 25,000 flight hours. Spectrum differences provide a partial explanation. A FASTRAN II analysis using a spectrum based on an in-flight strain measurement system known as AFDAS produced a shorter life again. Further work is underway to quantify the difference in the predictions due to spectrum differences, and that due to analysis techniques.

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Executive Summary

Fatigue cracking is a well known threat to the structural integrity of the RAAF's F-111 fleet. The high strength D6ac steel used in critical components such as the Wing Pivot Fitting is particularly susceptable to fatigue cracks. Structural integrity management for these areas is reliant upon the ability to accurately model and predict the behaviour of fatigue cracks which could occur.

Until recently, the RAAF have relied on the manufacturer, Lockheed Martin Tactical Aircraft Systems (LMTAS), to carry out these analyses on their behalf. In the light of the USAF withdrawing their F-111s from service, the RAAF have recently determined that it will not be possible to rely totally on LMTAS to conduct DADTA studies in the future to support the aircraft until the Planned Withdrawal Date (PWD), which may be as late as 2020. A goal has therefore been set to develop and establish a local Australian capability to carry out this work. DSTO and AMRL support is an essential element of this indigenous support capability. This report details work which has been undertaken to assist with the development of DSTO's fatigue crack growth modelling capability, with particular application to the F-111 weapon system.

A review and analysis of crack growth at a known fatigue critical location, the Wing Pivot Fitting lower plate at Fuel Flow Hole No 58 (DADTA Item 86) under RAAF F-111 fleet spectra was conducted. The goals were to extend crack growth analysis expertise and compare the results with those obtained by the manufacturer, Lockheed Martin Tactical Aircraft Systems (LMTAS). The results show a significant difference in the results obtained in this analysis and those obtained by the manufacturer. Further investigation into the exact spectrum used by LMTAS is planned to identify the cause of this difference. It was also found that although the spectrum developed from the Aircraft Fatigue Data Analysis System (AFDAS) data contained an insufficient number of flights to be judged representative of the RAAF F-111 fleet, the AFDAS system can provide a spectrum in a form suitable for analysis.

DSTO's fatigue crack growth modelling capabilities have been enhanced as a result of this work. This represents a significant step towards the final goal of the establishment of an indigenous support capability for crack growth modelling and damage tolerance analysis in support of the F-111 weapon system.

Contents

1. Introduction

Structural Integrity for the RAAF's fleet of F-111 aircraft is assured on the basis of a Durability and Damage Tolerance Assessment (DADTA). The DADTA process includes the identification of significant structural locations for which an assessment of the implications of structural damage, such as fatigue cracking, is carried out. The assessment process usually involves performing a crack growth and failure analysis using fracture mechanics. Until recently, the RAAF have relied on the manufacturer, Lockheed Martin Tactical Aircraft Systems (LMTAS), to carry out these analyses on their behalf. In the light of USAF withdrawing their F-111s from service, the RAAF have recently determined that it will not be possible to rely totally on LMTAS to conduct DADTA studies in the future to support the aircraft until the Planned Withdrawal Date (PWD), which may be as late as 2020. It has therefore been decided to develop and establish a local Australian capability to carry out this work. DSTO and AMRL have a major role to play in this regard, and the work reported in this document represents significant progress in establishing the required capability.

The DADTA studies, which have been conducted by LMTAS for many different F-111 models and roles, have identified hundreds of structurally significant locations. The locations have been selected on the basis of cracking observed either in test or service, and on the basis of an analysis which indicates that cracking could occur in service. In this report, one particular DADTA Item, known as DADTA Item 86 was selected for detailed examination.

DADTA Item (DI) 86 is in the Wing Pivot Fitting (WPF) lower plate. The cracking scenario is a chordwise surface flaw initiating on the inside (upper) surface of the lower plate adjacent to the centre spar fuel flow hole #58. The location is shown in Figure 1 (from Reference 1).

DI 86 arose because it was the location at which the A-4 right hand fatigue test wing failed due to a fatigue crack (References 2 and 3). The A-4 right hand wing fatigue test was conducted in 1969/70 to provide the fatigue substantiation for the F-111A aircraft. The test was performed using a spectrum considered to be representative of F-111A anticipated usage. Reference 11 summarised the crack growth curve and the fracture mechanics analysis which was performed and calibrated to the test result. LMTAS later performed predictive analyses for various F-111 models under various load spectra. An analysis was performed for the RAAF F-111C aircraft using an Australian developed load spectrum (References 4 and 5).

Previous work on DI 86 included a review of the A-4 fatigue test analysis using the tools available to AMRL and a comparison with the original LMTAS (then General Dynamics) results (Reference 6).

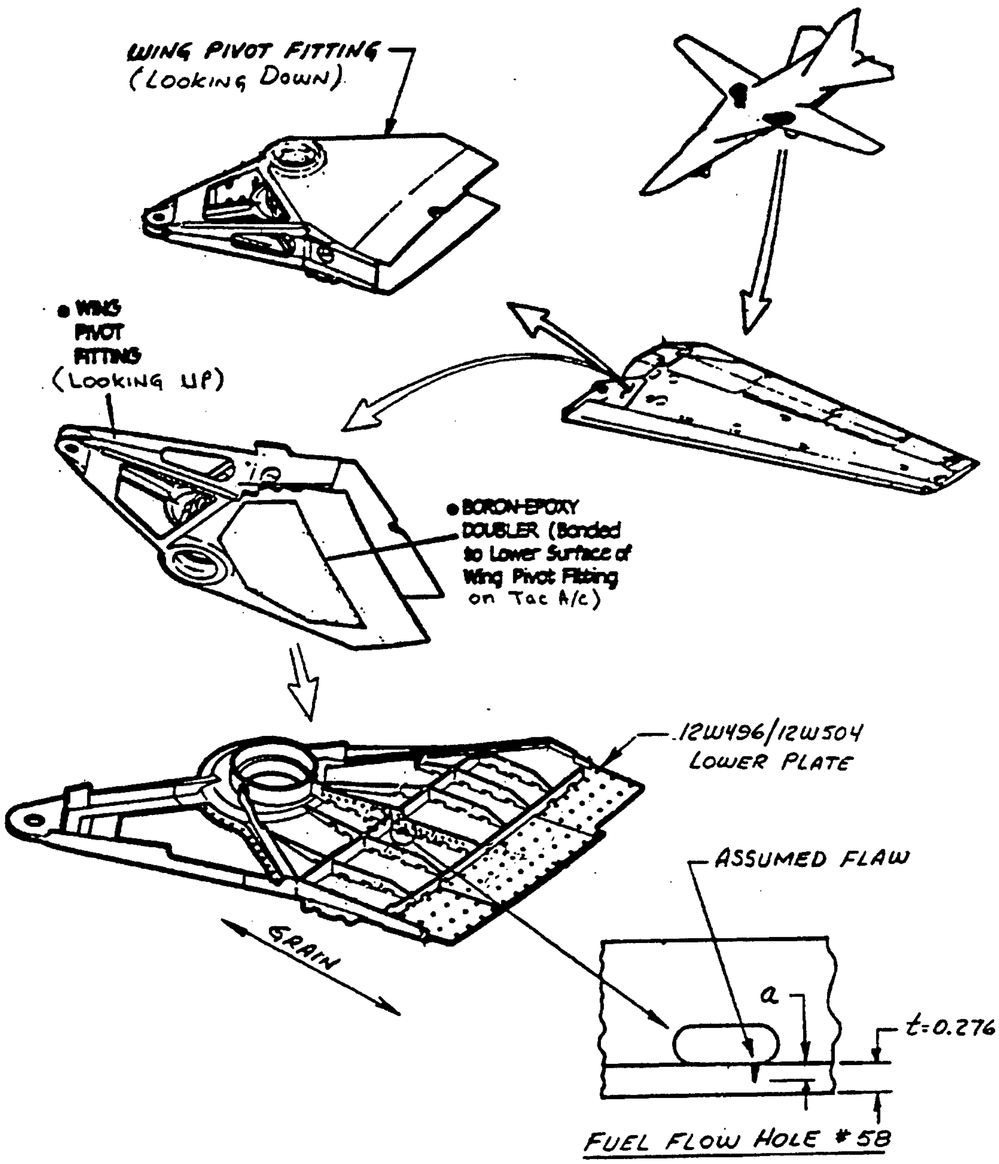

Figure 1. Location of DADTA Item 86

This report details the fatigue analysis of DI86 performed using,

a. The RAAF F-111C DATA spectrum, and

b. A more recently derived spectrum developed from the Aircraft Fatigue Data Analysis System (AFDAS)

A comparison of these results with the LMTAS analysis presented in Reference 5 is also conducted.

The purpose is to gain a full understanding of what LMTAS did in their analyses, and to develop and assess improved techniques where possible.

2. LMTAS Analysis

The LMTAS crack growth predictions for RAAF F-111C DI 86 are contained in Reference 4, dated 3 March 1994. Two analyses were conducted, one for a Wing Pivot Fitting (WPF) without a boron doubler applied and one with the boron doubler applied. As all F-111C aircraft in the RAAF fleet contain the boron doublers, only the second prediction was reviewed.

LMTAS performed the analysis using the ADAMSYS MODULE B2 software. The ADAMSYS software is based upon Linear Elastic Fracture Mechanics (LEFM), and includes stress intensity solutions for a range of configurations and loadings, using crack growth rate data derived from Forman, Modified Walker or Paris equations. Load interaction effects can be modelled using no retardation, Wheeler retardation or Generalised Willenborg Retardation.

According to Reference 7, DI86 crack growth was conducted as a surface flaw (variable crack aspect ratio, a/c) in a D6ac 220/240 Heat Treat Steel flat plate subjected to a JP-4 fuel environment at 10°F. A forman equation developed in FZS-12-494 and presented below was used by LMTAS as the crack growth rate input, while a Willenborg retardation model with a shut-off stress ratio of 2.5 was employed. The input plate and flaw dimensions and crack growth rate equations were :

Plate Width : 42 inches
Plate Thickness : 0.276 inches
Initial Crack Depth, a : 0.005 inches
Initial Crack Length, c : 0.005 inches

Forman equation for $\Delta K \leq 13$: $$\frac{da}{dN} = \frac{2.998 \cdot 10^{-9} (\Delta K)^{4.317}}{(1-R) \cdot 110 - \Delta K} \quad [1]$$

Forman equation for $\Delta K > 13$: $$\frac{da}{dN} = \frac{1.091 \cdot 10^{-6} (\Delta K)^{2.016}}{(1-R) \cdot 110 - \Delta K} \quad [2]$$

The applied load spectrum was derived from the RAAF F-111C DADTA spectrum developed by Hawker deHavilland Victoria and documented in Reference 5. LMTAS edited and truncated this original spectrum themselves before applying it on a cycle by cycle basis. DI 86 contains a stress gradient (tension + bending stresses), which is described by the following equation:

$$\sigma(\text{ksi}) = (8.9 - 11.0507 \times X) \times \text{WPBM} \qquad [3]$$

where X = depth, in inches, below the inner surface
WPBM = Wing Pivot Bending Moment in Millions of Inch Pounds (MIPS)

3. AMRL Analysis

The current AMRL analysis is conducted using the same specimen configuration and stress multipliers used by LMTAS. However, there are three major differences between the two analyses, these being crack growth prediction software, crack growth rate data and applied spectra.

3.1 Crack Growth Prediction Software

While LMTAS used the ADAMSYS software package, the current analyses performed at AMRL used the FASTRAN II - Fatigue Crack Growth Structural Analysis Program, written by J.C. Newman, Jr. FASTRAN II was the crack growth program of choice in this analysis due to its proven superior predictive abilities in previous analyses, documented in Reference 9. It is a life prediction code based on an analytical model of plasticity induced crack closure based on the Dugdale model representation for the plastic zone at the crack tip, modified to leave a wake of plastically deformed material along the crack surface. This program is significantly different from ADAMSYS because of the mechanistic modelling of closure, and consequently of load interaction effects. Stress Intensity Factor, K, is still the driving parameter for crack growth, but the concept of an effective stress range determined from the analytical crack closure model is used to account for both stress ratio and load sequence effects.

This approach is summarised for constant amplitude loading in Figure 2 below and explained at length in Reference 8. Due to closure effects, the crack does not fully open until an applied stress of σ_{op} is reached. The effective cyclic stress range is therefore reduced from $\Delta\sigma_{app}$ (applied stress range) to $\Delta\sigma_{eff}$ (effective stress range), and the effective stress intensity range is also reduced accordingly.

Annex A contains a sample FASTRAN II input file used in this analysis.

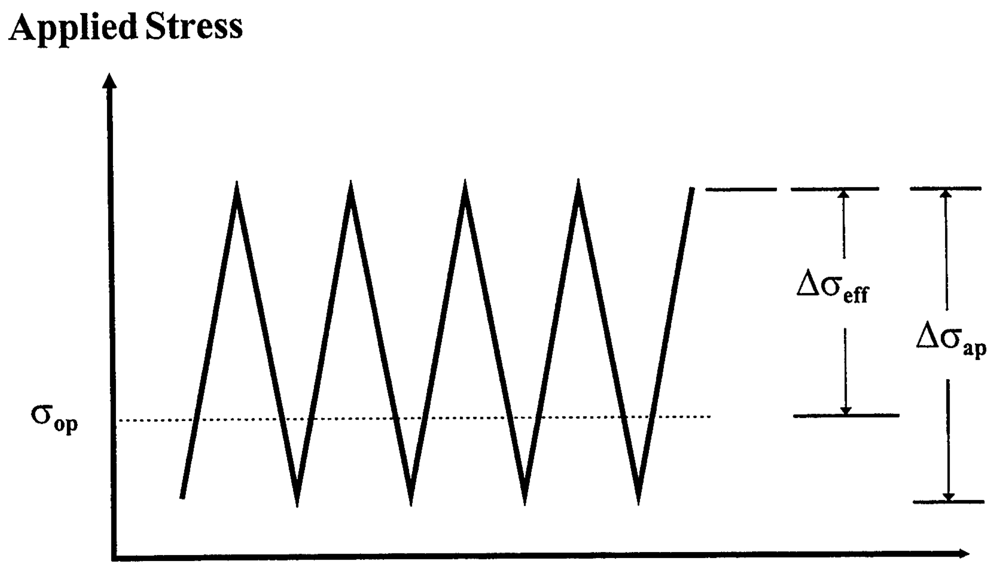

Figure 2. Effective Stress Range Concept for Constant Amplitude Loading

3.2 Crack Growth Rate Data

Although the source of the crack growth data used by LMTAS to construct the Forman equations they used is unknown at this point, it is reasonable to expect that they used the same data for D6ac 220/240 HT steel in a JP-4 fuel environment as presented in Reference 10. This report provides both experimental crack growth data for stress ratios from -1 to 0.8, as well as mean curves fitted by LMTAS. Hence, this crack growth rate data was used as the basis of FASTRAN II crack growth rate data input.

FASTRAN II requires the input of only one crack growth rate versus effective ΔK curve. This curve is produced by determining a line of best fit through the experimental crack growth rate versus effective ΔK data. The program DKEFFNEW determines the effective ΔK values based upon the crack growth rate specimen thickness, width, maximum applied stress for constant amplitude loading, stress ratio and the user specified constraint factor, α.

Of these variables, the constraint factor is the most important parameter. According to Reference 8, for ideal full plane strain conditions, $\alpha = 3.0$, while $\alpha = 1.0$ for full plane stress conditions. When analysing crack growth rate data from a specimen with a through crack, such as a compact tension or centre crack tension specimen, Newman (Reference 11) recommends a procedure whereby a high α (plane strain) is assumed for low crack growth rates where ΔK is low and there is high constraint. A low α is used at high crack growth rates in the constraint loss regime where ΔK is high. The actual constraint factor values are chosen to best collapse the crack growth rate versus ΔK curves for various stress ratios into one crack growth rate versus effective ΔK curve, which is then taken as the line of best fit.

In the ideal world, the above crack growth rate specimens would have the same thickness, and hence constraint, as the through crack specimen for which a prediction is required, and the crack growth rate data would collapse neatly onto one curve. Therefore, the same constraint factors can be used in DKEFFNEW to collapse the data and in FASTRAN II when performing the prediction.

However, in the case of DI 86, the crack is a surface flaw, not a through crack, where plane strain conditions ($\alpha = 3.0$) are generally assumed to exist for the whole life of the crack. Hence this condition should be used for the prediction, rather than the constraint factors best suited to the crack growth rate for the through crack specimens. Additionally, the specimen type, thickness, width and maximum applied stress is not known for some of the experimental crack growth rate data. Using the collapse of the experimental data where the specimen details were known (details from Reference 12), it was found that these specimen details had very little influence on the collapse of the data. Conversely, the constraint factors trialed had a large influence over the data collapse, especially at higher crack growth rates. No constraint factors were found that collapsed the data onto one curve without high scatter, though a high constant constraint factor ($\alpha = 3.0$) appeared to collapse the data as well as any other value. Therefore it was decided to construct a line of best fit through the effective crack growth rate data which had been collapsed using a constant constraint factor of 3.0. Reasonable arbitrary values were assumed for the specimen geometry details.

Using the same specimen details and constraint as the experimental data, the mean crack growth rate curves determined by LMTAS and given in Reference 10 were collapsed to effective curves using DKEFFNEW. It was found that the mean curve for R=0.65 produced a satisfactory line of best fit to the experimental data. Hence this effective mean R=0.65 curve was used as effective crack growth rate input to FASTRAN II with a constant constraint factor, α, of 3.0. The experimental data and LMTAS mean R=0.65 curve and subsequent effective data and curve are shown in Figures 3 and 4 respectively.

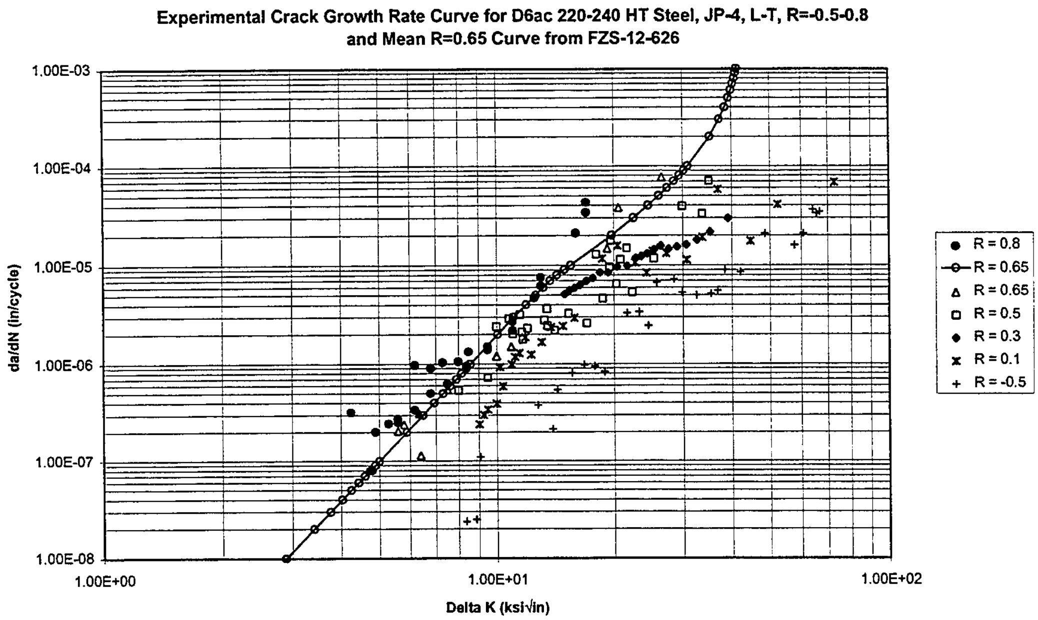

Figure 3. da/dN vs ΔK for D6ac Steel in JP-4 Fuel Environment

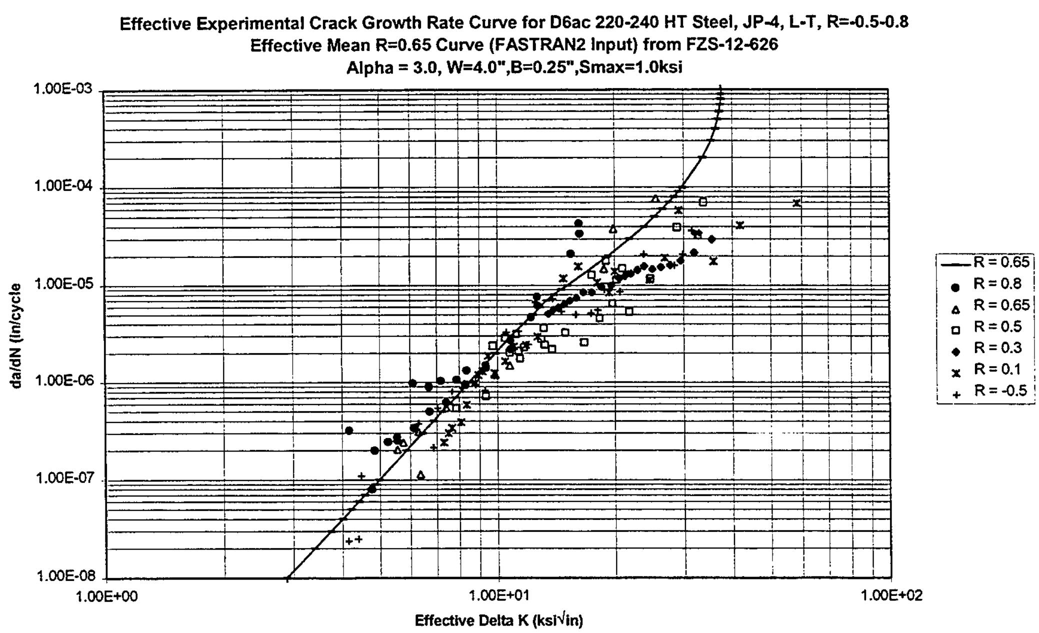

Figure 4. da/dN vs Effective ΔK with α=3.0 for D6ac Steel in JP-4 Fuel Environment

3.3 Load Spectra

Two load spectra, in the form of Wing Pivot Bending Moments (WPBM) were applied to DI 86. These WPBM's were scaled to stress at DI 86 and the stress gradient defined within the FASTRAN II input file. The first spectrum applied was the RAAF F-111C DADTA WPBM Spectrum as detailed in Reference 5. It was believed that this spectrum should produce a similar prediction to that made by LMTAS, as LMTAS used a derivation of this spectrum for their prediction. The second spectrum applied was an Aircraft Fatigue Data Analysis System (AFDAS) based spectrum, derived from more recent RAAF missions flown in 1994 and 1995.

3.3.1 RAAF F-111C DADTA WPBM Spectrum

The RAAF F-111C DADTA Spectra were specifically created for use by LMTAS to conduct the RAAF F-111C DADTA. The original spectra consisted of 200 flights flown between 1983 and 1988 (some repeated) making up approximately 500 flight hours, assembled by Hawker de Havilland Victoria using Multi Channel Recorder (MCR) data gathered from the RAAF fleet. The MCR was a device that measured twenty-four aircraft flight parameters, from which aircraft loads could be derived. Due to a file error, one flight was dropped from the original 200 flights, leaving a 499.7 flight hour spectra. For this particular analysis on DI 86, the WPBM spectrum was required. This spectrum consisted of 1780220 maximum-minimum cycles, which were range paired and blocked before entry into the FASTRAN II input file. One cycle was added at the start of the block so that the first maximum stress was greater than zero to prevent the program crashing. This spectrum should be consistent with the LMTAS spectrum used for the RAAF F-111C DADTA. It is known however that LMTAS modified the spectrum by filtering, editing, truncating and removing some flights.

3.3.2 AFDAS Based WPBM Spectrum

AFDAS is installed on a number of RAAF F-111 aircraft and was designed to replace the MCR fatigue monitoring system. This system measures strain at various locations on the aircraft, which can then be directly converted to stresses using transfer functions and stress-strain relationships. The measured strains were range paired during flight and Channel 1 strain data used to obtain the WPBM data. The spectrum itself consists of twenty-four flights from 1994 and 1995, making up 49.9 flight hours with 20113 cycles. The selection of flights that compose this spectrum is detailed in Reference 13, Annex C.

3.3.3 Comparison of Exceedence Diagrams

The RAAF F-111C DADTA, AFDAS and LMTAS WPBM exceedence diagrams are shown in Figure 5. The LMTAS exceedence diagram was established by taking points directly from an exceedence diagram published by LMTAS (Reference 4). A WPBM range exceedence diagram for the RAAF F-111C DADTA and the AFDAS WPBM spectra is displayed in Figure 6, where the range is the difference between the maximum and minimum WPBM in each cycle. An Nz exceedence diagram for the RAAF F-111C and AFDAS spectra, derived from RAAF F-111 EE360 fatigue meter sheets is presented in Figure 7, to enable a comparison between the two different spectra on the basis of fatigue meter exceedence data.

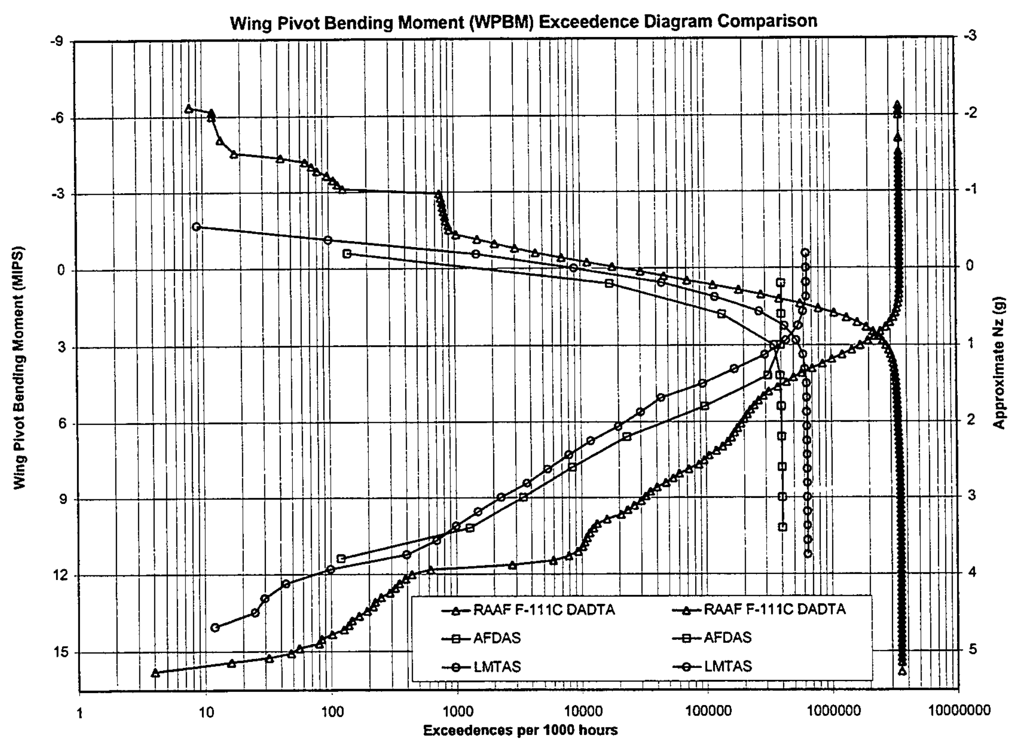

Figure 5. Wing Pivot Bending Moment Exceedence Diagram Comparison

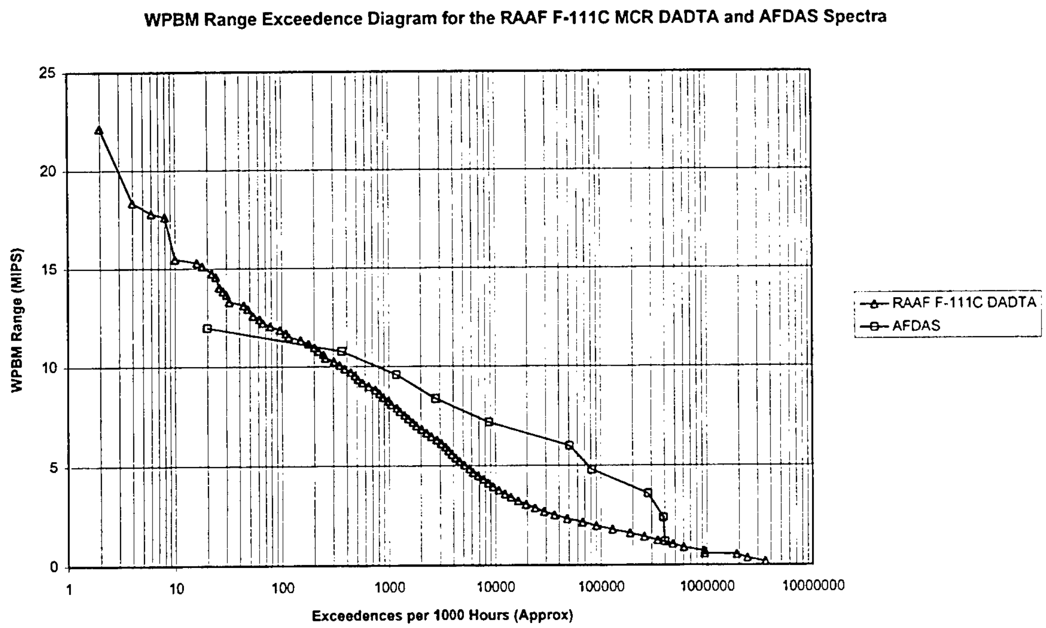

Figure 6. Wing Pivot Bending Moment Range Exceedence Diagram Comparison

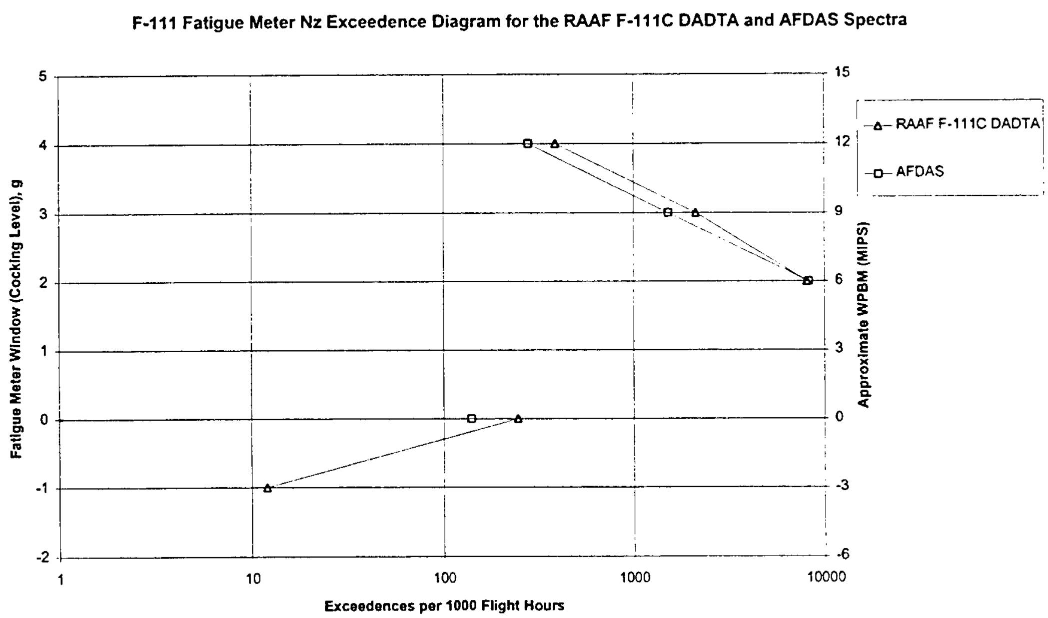

Figure 7. Nz Exceedence Diagram Comparison

4. Fatigue Crack Growth Predictions

Crack growth predictions for the LMTAS, RAAF F-111C DADTA and AFDAS spectra are summarised in Table 1 while crack growth curves are presented in Figure 8. The predictions for the RAAF F-111C DADTA and AFDAS spectra were obtained using FASTRAN. The LMTAS prediction was obtained using their ADAMSYS program and used a spectrum which was derived from the RAAF F-111C DADTA MCR sample (see Figure 5).

Table 1. Predicted Fatigue Lives in Hours for a Crack to Grow from a Depth/Length = 0.005 inches to a Crack Length of 0.17 inches

Fatigue Life Predictions for DI 86 Under Various Spectra, Life Estimation when Crack Length, c, equals 0.17"			
Spectrum	AFDAS	RAAF F-111C DADTA	LMTAS
Fatigue Life, Flight Hours	18563	25511	56896

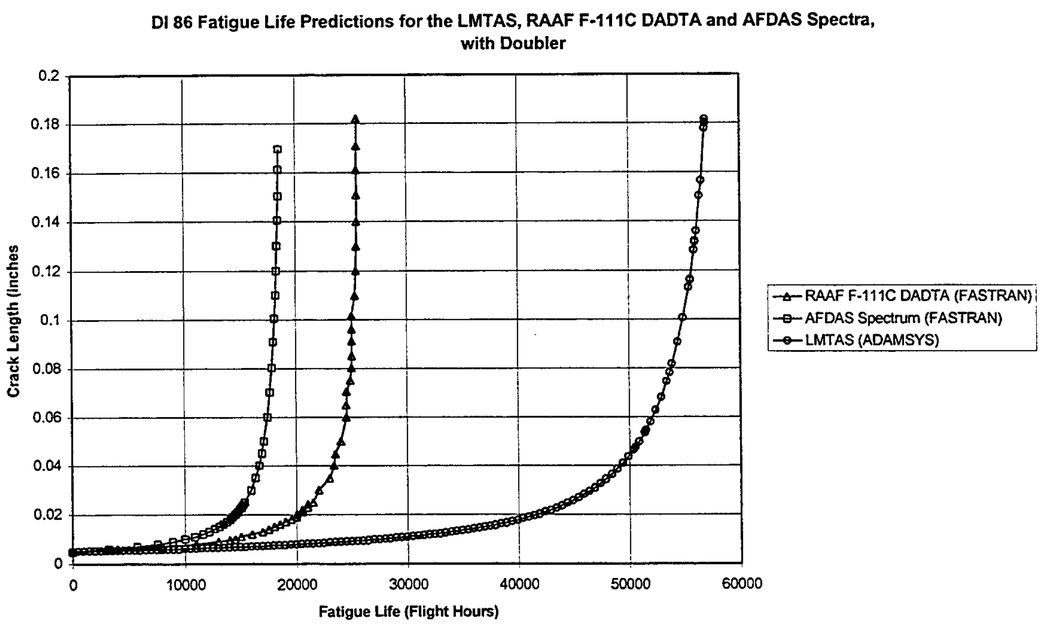

Figure 8. Fatigue Crack Growth Predictions

5. Discussion

The fatigue analysis prediction performed by LMTAS for the RAAF, using their version of the RAAF MCR F-111 DADTA spectrum, was not directly calibrated to any experimental result, though the retardation parameter may have been calibrated to another spectrum. The current analysis conducted using FASTRAN II, which produced a fatigue life prediction less than half that of LMTAS, raises some concern about the LMTAS result.

It is reasonable to assume that the specimen and material properties in the two analyses are similar enough not to significantly influence the results, as they are derived from the same source. The crack growth rate is, however, interpreted in a different way for each of the programs. The difference in the crack growth predictions is considered to be due to either fundamental differences between the models, spectrum differences, or both. Reference 9 concluded that large differences in fatigue life can occur due to relatively small variations in the applied load spectrum, and that the standard LEFM load interaction models, such as Willenborg used by LMTAS, may not properly predict these differences, even when calibrated to the original spectrum. It is also possible that the FASTRAN II code used in the current analysis may not correctly model the load interaction effects, despite previous consistent results.

It is known that LMTAS edited the original RAAF F-111 DADTA spectrum (as demonstrated by the difference in the exceedence diagrams in Figure 5), and as such, this spectrum is different to both the spectrum used in the current prediction and any spectrum used when calibrating the load interaction model (if calibrated at all). Hence the DI 86 fatigue prediction differences may be due to the spectrum variations and/or the load interaction models used.

The AFDAS based spectrum reduced the DI 86 fatigue life even further. This result is unexpected when considering the spectrum exceedence diagrams in Figure 5, where the AFDAS based spectrum appears to be much less severe than the RAAF F-111 DADTA spectrum. However, a better indication of the differences between the two spectra is given by Figure 6. This figure shows that the AFDAS based spectrum contains higher stresses at high exceedences, which is more damaging, yet almost no very high stress/low exceedence cycles which contribute significantly to retardation effects. The Nz exceedence diagrams in Figure 7 also indicate less high stress/low exceedence cycles in the AFDAS based spectrum. Hence the AFDAS based spectrum is more damaging with less retardation effects, which is consistent with a lower fatigue life.

Despite the fact that on the basis of the fatigue meter data (Figure 7), the AFDAS spectrum is similar to the F-111C DADTA sample, the AFDAS based spectrum cannot be considered representative of the RAAF fleet, and therefore cannot indicate a change in fleet loading in the years between the generation of the two spectra. This is because the AFDAS based spectrum was generated from only a small sample of twenty four

flights making up 50 flight hours. Such a small sample is unlikely to include infrequent high stress cycles that cause retardation. Additionally, the specific type of flying in this sample has not been analysed, and therefore cannot be proven to be representative of the type of flying encountered by the average aircraft in the fleet.

The approximate Nz or "g" levels shown on the right hand scale on Figure 5 indicate where the fatigue meter data is limited. There is a window at 4g, and the next window is 5.5g. Thus, significant WPBM events between approximately 11.9 and 16.3 MIPS are missed. It is therefore difficult to compare spectra on the basis of fatigue meter exceedence data only.

6. Conclusions and Recommendations

There is a significant discrepancy between the fatigue life predictions for DI 86 using the two RAAF F-111 DADTA spectra, and that obtained by LMTAS. This discrepancy can be traced to either the spectra or the fatigue life code and load interaction methods. As DI 86 inspection intervals are based upon the LMTAS prediction, it is important that the reason for this discrepancy be identified.

Efforts are currently underway to obtain the exact spectra applied by LMTAS in their prediction. Once this spectrum is obtained, it can be entered into FASTRAN II with the same input variables as in the current analysis. An informed decision should then be able to be made as to whether the spectrum and/or load interaction variations contributed to the difference in the life predictions.

The current AFDAS based spectrum sample is too small but as additional AFDAS data is collated, the AFDAS based spectrum will be updated. When a large enough sample is attained, a direct comparison with the RAAF F-111 DADTA spectrum will be conducted, and any consequences with regard to the F-111 inspection procedures reviewed at that time.

7. Acknowledgments

The authors wish to acknowledge the assistance of FLTLT Greg Hoffman, RAAF F-111 Technical Liaison Project Officer who submitted queries concerning DI 86 to LMTAS. The assistance and advice provided by Drs. L.R.F. Rose and C.H. Wang from AMRL, and Drs. J.C. Newman and D.S. Dawicke from NASA Langley, Virginia USA, was also greatly appreciated.

8. References

1. "DADTA : F-111 A/E/D/F and FB-111A Final Analysis Details", FZS-12-495, Revision A, General Dynamics, 29th May 1987.
2. "Fracture Mechanics Volume II - Analysis for Operational Aircraft Usage", FZM-12-13467, General Dynamics, 15th July 1973.
3. "F-111 A-4 Right Hand Wing Fatigue Test 30.5 Blocks Report", FZS-12-325, Volume I of III, General Dynamics, 29th December 1970.
4. Lockheed Fort Worth Company (LFWC) Memo from Brad Prevallet to Thomas Urquhart III, "Corrections to ADAMSys Crack Growth Prediction Results for RAAF F-111C DADTA Item 86 Without the Doubler", dated 7th March 1994.
5. "F-111 DADTA Spectrum Generation Task Summary", AA-1000, Hawker de Havilland, 1992-1993.
6. Murtagh, B.J. and Walker K.F., "Comparison of Analytical Crack Growth Modelling and the A-4 Wing Test Experimental Results for a Fatigue Crack in an F-111 Wing Pivot Fitting Fuel Flow Hole Number 58", DSTO-TN-0108, September 1997.
7. E-mail from Thomas Urquhart III (LMTAS) to Kevin Walker (AMRL), "Details on DI86", dated 24th March 1994.
8. Newman, J. C. Jr., "FASTRAN II - A Fatigue Crack Growth Structural Analysis Program", NASA TM-104159, February 1992.
9. Walker, K., "An Evaluation of Empirical and Analytical Models for Predicting Fatigue Crack Propagation Load Interaction Effects", Presented at the 1997 USAF ASIP Conference, San Antonio, Texas, USA, December 1997.
10. "Metallic Material Data for F-111 Durability and Damage Tolerance Analysis", FZS-12-626, LMTAS, 30th April 1996.
11. Newman, J.C. Jr., Phillips, E.P. and Swain, M.H., "Fatigue Life Prediction Methodology Using Small-Crack Theory", NASA TM-110307, January 1997.
12. "Crack Behaviour in D6ac Steel - An Evaluation of Fracture Mechanics Data for the F-111 Aircraft", MCIC-72-04, Metals and Ceramics Information Centre/Air Force Materials Laboratory, Ohio, January 1972.
13. Murtagh, B., "Development of a Technique to Compare Nz Data from AFDAS and Fatigue Meter for F-111 Aircraft", AMRL Letter Report, File Reference B2/03/112 Pt2(45) dated 12 June 1997.

Appendix A: Input Data for FASTRAN2 Crack Growth Program

The following input file pertains to the DI86 crack growth prediction under the AFDAS spectrum. For the MCR spectrum case, the AFDAS blocked spectrum details in the last section of the input file are replaced with the MCR blocked spectrum data.

```
Surface Flaw Under Combined Tension and Bending,
AFDASMidRangeCaseSpectrum(20113cycles)
cstamp    200.0
D6ac(220-240HT)Steel,JP-4,L-T(LMTAS data-FZS-12-626-mean curve-R=0.65)
 190.0    220.0   29000.0   0.32    3.0   0   0   1.0
 1
3.5000E-09  2.60     1.0      0.0    9999     200.0    0.0
  13  0
2.881   1.00E-08
5.857   2.00E-07
10.86   3.00E-06
19.28   2.00E-05
29.85   1.00E-04
33.69   2.00E-04
35.42   3.00E-04
36.38   4.00E-04
36.96   5.00E-04
37.33   6.00E-04
37.89   1.00E-03
37.90   4.00E-03
37.91   1.00E-02
1000   20   1   1   0.005
  0   2   0   1   1   0   0
  21.0     0.276   0.005   0.005    0.005    0.005   0.0     0.0
  0.276
  0.2068
  0.0      0.0
   0  0.0
 1   1   0   0
  7.375
1   46  1
0.599146815    -0.599146815   7
5.392321334    -0.599146815   1
6.590614964    -0.599146815   7
7.788908594    -0.599146815   6
8.987202224    -0.599146815   9
10.18549585    -0.599146815   4
11.38378948    -0.599146815   2
```

1.797440445	0.599146815	310
2.995734075	0.599146815	289
4.194027705	0.599146815	97
5.392321334	0.599146815	60
6.590614964	0.599146815	26
7.788908594	0.599146815	18
8.987202224	0.599146815	14
10.18549585	0.599146815	8
11.38378948	0.599146815	2
2.995734075	1.797440445	3850
4.194027705	1.797440445	1400
5.392321334	1.797440445	373
6.590614964	1.797440445	151
7.788908594	1.797440445	71
8.987202224	1.797440445	21
10.18549585	1.797440445	14
4.194027705	2.995734075	9263
5.392321334	2.995734075	1347
6.590614964	2.995734075	170
7.788908594	2.995734075	44
8.987202224	2.995734075	8
10.18549585	2.995734075	3
5.392321334	4.194027705	1957
6.590614964	4.194027705	120
7.788908594	4.194027705	17
8.987202224	4.194027705	6
10.18549585	4.194027705	1
6.590614964	5.392321334	262
7.788908594	5.392321334	31
8.987202224	5.392321334	3
10.18549585	5.392321334	4
7.788908594	6.590614964	64
8.987202224	6.590614964	9
10.18549585	6.590614964	5
8.987202224	7.788908594	38
10.18549585	7.788908594	3
10.18549585	8.987202224	16
11.38378948	8.987202224	1
11.38378948	10.18549585	1

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B. J. Murtagh and K. F. Walker

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19. ABSTRACT

This report details a comparison of fatigue growth predictions for a fatigue crack in the lower plate of the F-111 Wing Pivot Fitting, adjacent to Fuel Flow Hole No 58. This is a known fatigue critical location and is designated as DI 86. Fatigue analysis using conventional fracture mechanics techniques and empirical retardation models performed by the manufacturer, Lockheed Martin Tactical Aircraft Sytems (then General Dynamics), predicted a fatigue life of approximately 57,000 flight hours. An equivalent analysis was conducted using the analytical crack closure code, FASTRAN II, and this resulted in a life prediction of about 25,000 flight hours. Spectrum differences provide a partial explanation. A FASTRAN II analysis using a spectrum based on an in-flight strain measurement system known as AFDAS produced a shorter life again. Further work is underway to quantify the difference in the predictions due to spectrum differences, and that due to analysis techniques.

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